Mountain Meadow Management: 12 Years of Variety, Fertilization, Irrigation, and Renovation Research

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The cover photograph, taken about 1903, is of the YU ranch in Big Horn County, Wyoming. Photograph courtesy of the Wyoming State Archives and Historical Department.

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ABSTRACT

Mountain meadows play a vital role in livestock production in the West, occupying over 4 million acres and providing over 5.5 million tons of forage per year. However, the level of management on these meadows is very low; only 16 percent receive any nitrogen fertilizer, and over 25 percent are still occupied by unimproved native vegetation. Economic constraints and land ownership patterns account for some of this poor management, but lack of reliable information on the results of improved management contributes significantly.

Studies of forage varieties; rate, date of application, and source of nitrogen and other fertilizer elements; and types of water management were conducted at nine locations in Wyoming from 1956 through 1968. These results have not been reported before, although they are as useful now as when the research was conducted.

Reseeding of meadows to creeping foxtail, meadow foxtail, reed canarygrass, meadow bromegrass, or intermediate wheatgrass increased forage production over that of unimproved meadows. Introduced grasses responded to N rates up to 240 lb/acre. Alfalfa-grass mixtures produced as much forage as grass plus 100 to 300 lb N/acre; however, water control, including provision for drainage as well as control of application, is essential for maintenance and maximum yield of introduced grasses and legumes.

Season of application and N source had little consistent effect on forage yields, except when apparent sulfur deficiencies caused forages to respond more strongly to ammonium sulfate than to other N sources. Fertilizer should be applied when soil moisture conditions permit and the operation fits best into the schedule of other ranch operations. Crude protein content was sometimes increased by N fertilizer, but date and source had little effect.

Temperature greatly affected forage production and response to nitrogen. Each forage species required an optimum number of degree days per growing season for maximum forage production; production was reduced if the number of degree days was more or less than the optimum. The optimum number of degree days was similar at all N rates.

Several areas need further research. They include (1) methods of reseeding and renovating meadows; (2) nutrient cycling in wet meadow soils; (3) interactions of nutrient availability, temperature, and soil-water relationships on forage phenology, yield, and quality; and (4) seasonal growth patterns and optimum grazing and harvesting schedules. Results of this research should be incorporated into verifiable mathematical models that can serve as a basis for management recommendations.

KEYWORDS: Livestock production, forage management, nitrogen fertilizer, reseeding.

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MOUNTAIN MEADOW MANAGEMENT: 12 YEARS OF VARIETY, FERTILIZATION, IRRIGATION, AND RENOVATION RESEARCH

By R. H. Hart, H. R. Haise, D. D. Walker, and R. D. Lewis[1]

INTRODUCTION

Mountain meadows or high-altitude wet meadows occupy over 4 million acres in the Western United States and provide approximately 5.5 million tons of forage per year (U.S. Forest Service *1972*).[2] Meadow sites vary from narrow strips along small streams to vast areas of seasonally flooded plains along major rivers. Most of the meadows are flooded during peak runoff in spring and early summer, but are fairly dry in late summer and fall; however, a few are boggy all year round. Most are at altitudes above 6,000 feet, hence the terms "mountain meadows" or "high-altitude meadows."

Native vegetation is predominantly sedges, rushes, and grasses, but some clovers, other forbs, and a few phreatophytic shrubs may be found. Vegetative composition is largely determined by depth and duration of flooding, but can be manipulated by water control, fertilization, cutting and grazing management, and reseeding.

Mountain meadows play a vital role in livestock production in the West. Traditionally, cattle and sheep graze in the summer on Federal land administered by the Bureau of Land Management or the U.S. Forest Service, or on privately owned rangeland. During the winter, stock are fed hay cut from improved or native meadow, or are grazed on the stubble remaining or aftermath produced after hay harvest on meadows. Stocking rate on Federal ranges, however, has been decreased to prevent further range deterioration, improve range condition, improve water quality, and provide additional forage for big game and wild horses. Large acreages have been withdrawn from grazing for recreational uses, and environmental groups have forced management decisions making it impossible to maximize forage for livestock use. Therefore, the need for optimum forage production from mountain meadows is greater than ever.

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[2] The year in italic, when it follows the author's name, refers to Literature Cited, p. 24.

R. D. Lewis increased forage production of a mountain meadow near Pinedale, Wyo., from 0.5 to 2.8 tons of hay per acre per year by renovation and a minimal amount of land smoothing (Kruse *1979*). A further increase of hay yield to 4.4 tons/acre was achieved by controlling irrigation and applying nitrogen fertilizer. N fertilization increased forage production in many studies, but response was affected by plant species, climatic conditions, plant vigor, and rate of N application (Eckert *1975*). Introduced forage species responded more strongly to N under intermittent flood irrigation than under continuous flooding, but the method of irrigation had little effect on the response of native grasses, sedges, and rushes (Lewis *1957*, Siemer and Rumburg *1975*). Differential responses to spring and fall N applications have been credited to differences in winter snow cover and soil temperatures (Seamands *1971*). Forage yields on mountain meadows in Colorado were strongly positively correlated with air temperature (Siemer et al. *1972*).

In spite of the demonstrated benefits of fertilization and introduction of improved forage species, only 16 percent of the total area of mountain meadow receives any N fertilization (U.S. Forest Service *1972*), and over a million acres of meadow hay land are occupied by the original native species (Jacobs and Kearl *1979*). Part of the explanation for the low level of mountain meadow management lies in economic constraints and land ownership patterns; however, it is likely that a lack of reliable information on the results of improved management has been a major factor in the reluctance of ranchers to adopt such management practices.

A series of experiments dealing with fertilization, renovation, reseeding, and water management of mountain meadows was carried out between 1956 and 1968 at nine locations in Wyoming by Walker, Lewis, and Haise. Hart assisted with analysis and interpretation of the data, and prepared this summary of the previously unpublished results of these studies, which are as useful today as they were when they were made.

STUDY SITES AND EXPERIMENTAL PROCEDURES

All experiments were conducted cooperatively with ranchers in the vicinity of Jackson, Daniel, Boulder, Big Piney, Saratoga, Encampment, Pinedale, McFadden, and Laramie, Wyo. (fig. 1). Altitude, precipitation, and temperature data for these towns or for the nearest town with an official weather station are shown in table 1. All locations are characterized by altitudes of 6,200 to 7,300 feet, short growing seasons with warm days and very cool nights, and long cold winters with varying periods and amounts of snow cover. Soils are loamy sands, sandy loams, or gravelly loams underlain by gravel and cobbles at 14 to 30 inches below the surface.

Nitrogen Source Study

This study was located at four sites: the Finch ranch near Encampment, the Roy Simms ranch near McFadden, the Edgar Loban ranch near Laramie, and the Mowery ranch near Saratoga. Vegetation on all sites was a mixture of native sedges and

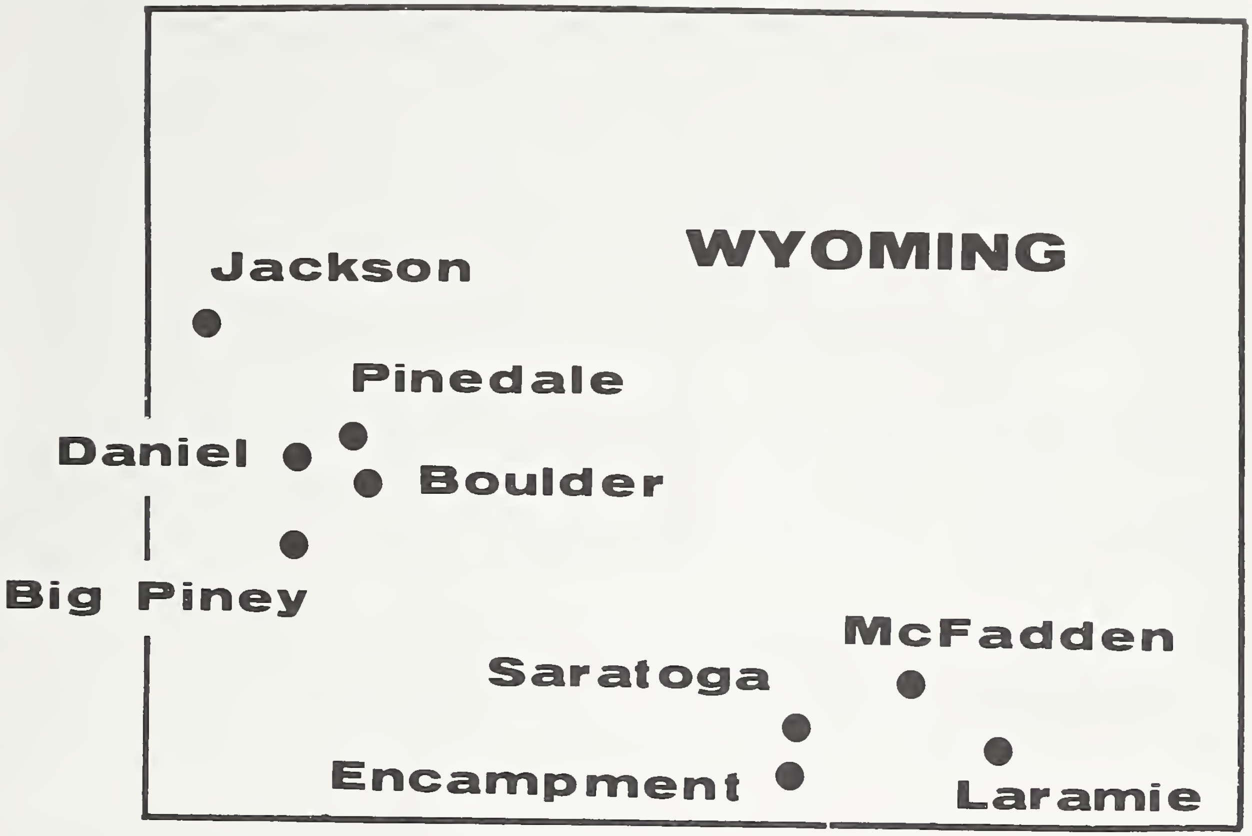

Figure 1.--Location of study sites in Wyoming.

rushes with some introduced bromegrass, timothy, and alsike clover.[3] A small amount of alfalfa was in the meadow at Encampment.

Ammonium nitrate, ammonium sulfate, or anhydrous ammonia were applied at 80, 120, or 240 lb N/acre to plots 15 by 30 feet, arranged in randomized complete blocks with four replications. Ammonium nitrate and sulfate were broadcast in May, and ammonia was applied in October at depths of 3 to 4 inches. Unfertilized check plots were included. All areas were flood irrigated from late May or early June until late June or early July. Soil water tension readings taken at McFadden and Laramie in 1957 indicated the soil was saturated throughout the irrigation period.

Hay was harvested in late July or early August, leaving about a 2-inch stubble. A strip 2 feet wide was cut the length of each plot with a sickle mower, and the forage was weighed. Subsamples were taken and ovendried to determine dry matter content and were later analyzed for crude protein content by the Kjeldahl method.

[3] Scientific names of all plant species are given in appendix table 5.

Table 1.--*Altitude, mean annual precipitation, and monthly mean high and low temperatures during the growing season at Wyoming study sites or nearest weather station*

Location	Altitude	Years of records	Precipitation	Mean high/mean low					
				Apr.	May	June	July	Aug.	Sept.
	Feet	*Number*	*Inches*	-------------*Degrees Fahrenheit*-------------					
Big Piney	6,800	30	8.50	51/20	62/29	70/36	80/39	78/35	69/27
Encampment	7,300	17	15.52	54/27	66/35	75/43	83/49	82/47	73/39
Jackson	6,200	58	15.22	52/24	62/30	71/36	82/40	80/38	70/31
Laramie[1]	7,200	30	11.14	51/28	61/37	72/45	79/52	77/50	69/42
Pinedale[2]	7,200	47	11.23	50/20	59/28	70/36	79/41	76/38	67/30
Saratoga	6,800	57	9.58	53/27	65/34	74/42	83/48	81/46	72/37

[1] 35 miles southeast of McFadden.
[2] 11 miles east of Daniel, 12 miles northwest of Boulder.

Grass Species with Nitrogen or Legumes

Meadows on the Ivan Sheffy ranch near Boulder and the Roy Simms ranch near McFadden were cleared, plowed, and seeded in 1957 and 1958, respectively, following broadcast application of treble superphosphate at 88 lb P/acre. Common meadow foxtail, 'Garrison' creeping foxtail, Russian wildrye, 'Manchar' smooth bromegrass, 'Amur' intermediate wheatgrass, tall wheatgrass, 'Ioreed' reed canarygrass, tall fescue, and timothy were seeded at both locations. In addition, 'Greenar' intermediate wheatgrass, 'Regar' meadow bromegrass, and orchardgrass were seeded at McFadden. The grasses were seeded in pure stands and in mixtures with 'Ladak' alfalfa, alsike clover, 'Ladino' white clover, mammoth red clover, Siberian red clover, zigzag clover, clover lupine, cicer milkvetch, and sickle milkvetch. Pure grass stands were seeded in plots 7 by 20 feet, and grass-legume mixtures in plots 7 by 7 feet. Ammonium sulfate at 0, 80, 160, or 240 lb N/acre was broacast on the grass plots each year, half in late April or early May and half in June. The design was a split plot, with grasses as main plots and legumes or N rates as subplots with three replications.

At Boulder, a sprinkler irrigation system applied 1.5 inches of water every 5 to 7 days from mid-May to mid-September. An average of 27.2 inches of irrigation water was applied each year. At McFadden, irrigation was by flooding, but water was available only until late June. Each year, 4 to 6 inches of water was applied in three or four irrigations.

At McFadden, hay was cut once each year in early July. At Boulder, two cuttings were taken in mid-July and early September. A strip 2 feet wide was cut, leaving a 2-inch stubble the length of each plot, and the forage was weighed. Subsamples were taken for dry matter and crude protein determinations.

Nitrogen Rate, Date, and Source Study

This study was located on meadows at the Joe Budd ranch near Big Piney, the Max Baroff ranch near Daniel, the Edgar Loban ranch near Laramie, and the Gerritt Hardeman ranch near Jackson. All the meadows included tufted hairgrass, timothy, and alsike clover. In addition, meadows included significant amounts of Kentucky bluegrass and redtop at Big Piney; bromegrass, intermediate wheatgrass, and some alfalfa at Daniel; bromegrass and orchardgrass at Jackson; and native sedges and rushes at Laramie. Treble superphosphate was broadcast at 88 lb P/acre on all sites at the beginning of the experiment.

Ammonium nitrate, ammonium sulfate, or urea were broadcast each year at each location at 0, 80, or 160 lb N/acre in April, in September, or in a split application of half in April and half in June. Plots were 20 by 70 feet at Laramie and 15 by 29 feet at the other locations. Design was a complete randomized block, with eight replications at Laramie and three replications at the other locations.

At Jackson and Laramie, the experimental area was naturally subirrigated, with soil water content above field capacity through May and June and perhaps later at Jackson. Flood irrigation was used at Big Piney and Daniel. Water was applied for 12 to 36 hours, with 10 to 14 days between irrigations (both intervals varied with water supply between locations and years) in June and July.

Hay was cut in late July or early August. A 2-foot strip was cut the length of each plot, leaving about 2 inches of stubble. Forage was weighed and sampled for dry matter and crude protein determination.

Grasses, Legumes, Nitrogen and Phosphorus Rates, and Irrigation Methods

This study was conducted on a native meadow on the Phillip Marincic, Jr., ranch near Pinedale from 1964 to 1968. In the spring of 1964, circular plots 3 ft in diameter were marked out, and the top 6 inches of soil was removed. This soil was passed through a grinder and replaced on each plot. Plots then were seeded to five grasses ('Garrison' creeping foxtail, common meadow foxtail, 'Ioreed' reed canarygrass, 'Manchar' smooth bromegrass, or 'Latar' orchardgrass), three legumes ('Tetra' alsike clover, 'Dollard' red clover, or cicer milkvetch), and all possible grass-legume mixtures. Plots of native meadow also were marked out.

Superphosphate at 85 lb P/acre was mixed into the soil from all plots before it was replaced (broadcast on native plots), and ammonium sulfate at 40 lb N/acre was applied to the native and grass plots soon after the emergence of the latter. In 1965 through 1968, ammonium sulfate at 50, 100, or 200 lb N/acre was applied to all grass plots in May each year. Legume plots received superphosphate at 85 lb P/acre at the same time or no P.

Half the experimental area was irrigated by continuous flooding from mid- to late May until late July each year. Water depths varied up to 2.5 inches. The remaining area was subirrigated by water movement from the flooded area; drainage ditches and sump pumps maintained the water table at approximately 8 inches

below the surface throughout the irrigation season. All grass-fertilizer combinations were replicated three times in a randomized complete block on each irrigation treatment. Legumes and legume-grass mixtures were seeded only on the subirrigated area in a completely randomized block with three replications.

Water was carried to the plot area via a 4-inch rubber line. In 1966 and 1967, incoming flow rate was measured with a Sparling meter and runoff was measured through a 3-inch Parshall flume with a water stage recorder.

Hay was cut in late July or early August, when the grasses were in the soft dough stage. Forage was cut from the entire area of each plot with power shears, leaving about a 2-inch stubble. Subsamples were taken for dry matter and crude protein determination. After clipping, distance from the center of each grass plot to the tiller of that grass farthest from the center was measured, as an estimate of the rate of encroachment of that grass into the native meadow.

Presentation of Results

Fertilizer rates are expressed in pounds of elemental N or P per acre. To convert P rates to the older P_2O_5 form, multiply by 2.3. All hay yields are given in tons of ovendry matter per acre. Protein contents and yields, determined by the Kjeldahl method, are also on an ovendry basis.

Data were analyzed statistically to determine if observed differences among treatments, species, or fertilizer rates were real or due to chance variation. If analysis showed less than 1 chance in 20 that all differences were due to chance, we used further analysis to identify the true or "significant" differences. In the tables and figures, data are labeled with letters of the alphabet; if two numbers have no letters in common they are significantly different. Thus, yields labeled "a" and "b" are truly different, but yields labeled "ab" and "bc" are not, and we assume that any difference between them is due to chance.

We also calculated equations to describe effects of temperature and fertilization on yield and protein content. The statistic "R^2" indicates how closely the equations fit the data. If $R^2 = 1.00$, yield or protein content agree exactly with the values predicted by the equation; if $R^2 = 0.00$ there is no agreement at all. Again, we use statistical analysis to see if the agreement is real or due to chance. If there is less than 1 chance in 100 that the agreement is due to chance, we label R^2 with two asterisks (**); if there is more than 1 chance in 100, but less than 1 chance in 20, we use one asterisk (*).

RESULTS AND DISCUSSION

Nitrogen Source Study

The response of hay yield to N rate was linear up to 160 lb N/acre for all three sources at Laramie, Encampment, and Saratoga (fig. 2). There were no significant differences among sources at Laramie. At Encampment and Saratoga,

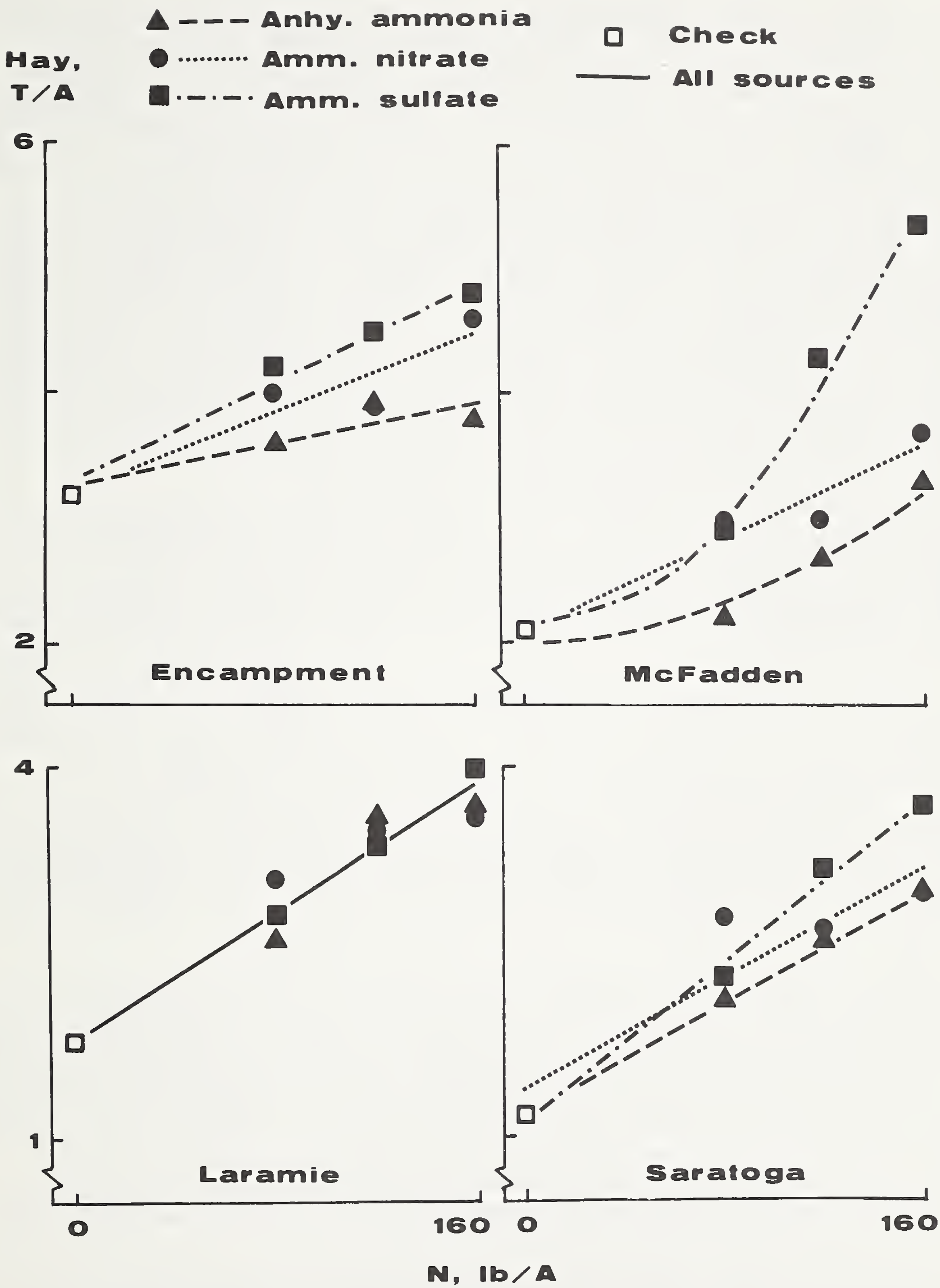

Figure 2.--Response of mountain meadow hay yields to 0, 80, 120, or 160 lb N/acre from three sources at four locations, 1956-57.

ammonium sulfate applied in the spring generally gave higher yields than anhydrous ammonia applied in the fall. The relative response to the different sources followed the same pattern at McFadden, but the response to anydrous ammonia, and particularly to ammonium sulfate, was nonlinear, with yields increasing more rapidly as N rate increased. Equations of the response curves are given in appendix table 6.

The superiority of ammonium sulfate at three locations may be due to greater N loss from ammonium nitrate through leaching of nitrate; however, the strong response to ammonium sulfate at McFadden may indicate a sulfur deficiency. In addition to its vital role in plant metabolism and protein synthesis, S also affects iron and molybdenum uptake by plants. No S response was noted at two locations near Gunnison, Colo. (Rumburg et al. *1972*), but Walker and Lewis (unpublished data) noted a strong response of alfalfa to S applied as gypsum on a mountain meadow near Boulder, Wyo. Because of this variability in apparent response to S, meadow soils should be tested for sulfur before making fertilizer recommendations. The poor performance of anhydrous ammonia at three locations might be attributed to losses through volatilization (if the soil were dry at the time of application) or to leaching.

N fertilization had no significant effect on crude protein content at any location. Protein content, averaged over all rates and sources, was 10.1, 7.7, 7.3, and 7.5 percent at Encampment, McFadden, Laramie, and Saratoga, respectively. The alfalfa in the Encampment meadow raised the protein content of the forage considerably.

Grass Species with Nitrogen or Legumes

All legumes, except alfalfa, winterkilled during the first winter at McFadden. At Boulder, alsike, ladino, mammoth red, zigzag, and Siberian red clovers and sickle milkvetch winterkilled the first winter, and clover lupine and cicer milkvetch died during the second winter. Tall fescue and timothy winterkilled at both locations, while tall wheatgrass did so at Boulder and reed canarygrass and orchardgrass did so at McFadden. No yields are reported from those species, even though 1 or 2 years of data were taken.

Most grasses responded linearly to N at Boulder, but yield responses at McFadden were significantly nonlinear, with yield response decreasing as N rates increased (fig. 3 and appendix table 7). Lack of water, not N, may have limited yield at high N rates at McFadden. If irrigation water supply had been adequate to produce two cuttings at McFadden, the higher rates of N might have been utilized more efficiently, and response would also have been linear at this location. Russian wildrye was an exception to the general pattern, showing a linear response to N at both locations and yields much lower than those of the other grasses. Meadow bromegrass, meadow foxtail, and reed canarygrass tended to produce somewhat less hay than creeping foxtail, 'Manchar' smooth bromegrass, or either of the wheatgrasses.

We used the N response curves to calculate the amount of N required to produce grass hay yields equal to yields of the equivalent alfalfa-grass mixture. These are the N equivalent values (Hart et al. *1977*), which appear in table 2. Note that meadow foxtail plus alfalfa at McFadden produced more hay

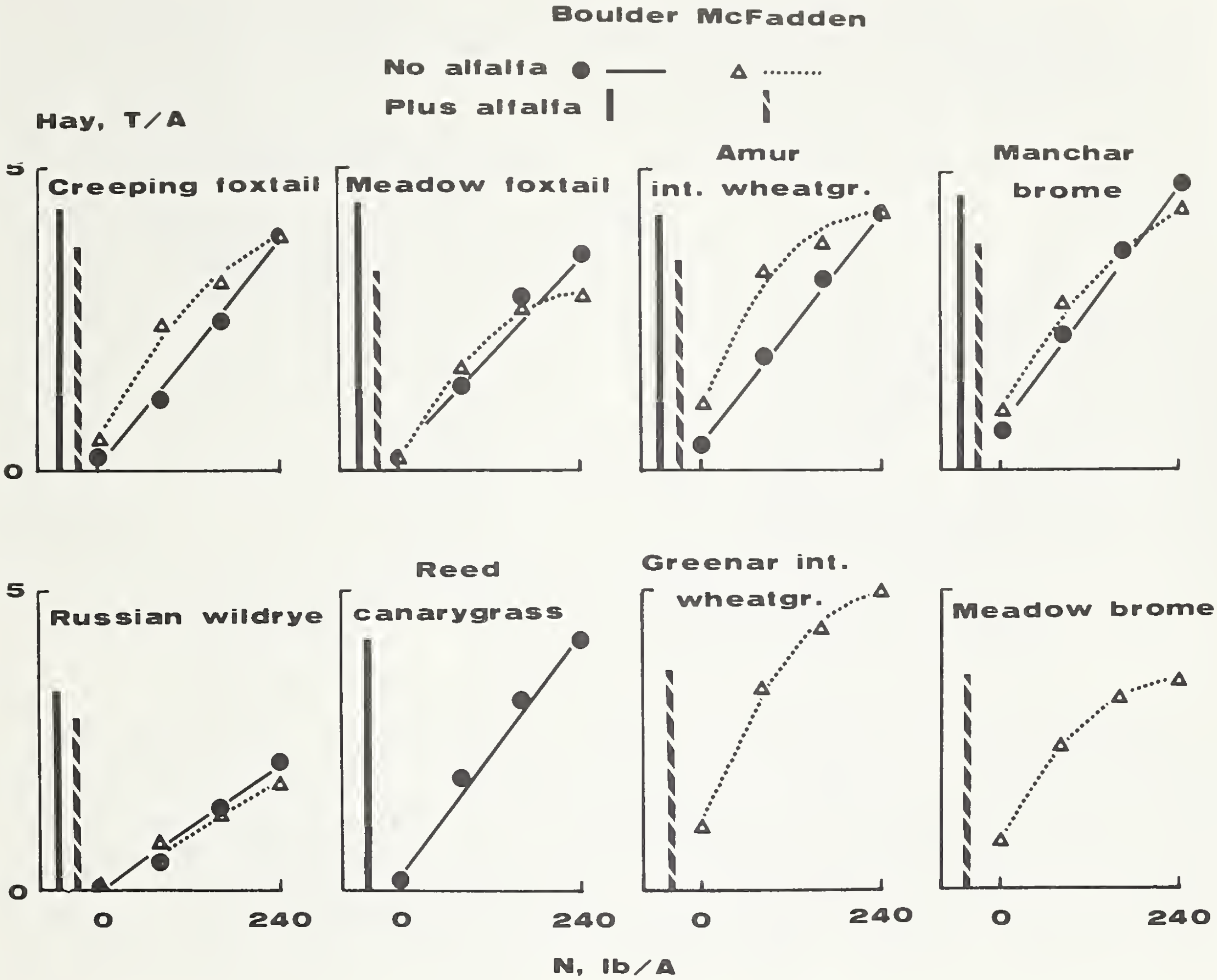

Figure 3.--Hay yields of grasses fertilized with 0, 80, 160, or 240 lb N/acre and of grass-alfalfa mixtures (Boulder, 1958-62, and McFadden, 1959-61).

than the maximum predicted at 230 lb N/acre by the N response curve, so we can only state that the N equivalent is over 230 lb N/acre. The N equivalent values for Russian wildrye are inflated because wildrye responded so poorly to N, yet alfalfa produced very well in association with wildrye. When irrigation is controlled as in this study, alfalfa in the mixture replaces 100 to 300 lb N/acre.

Species adapted to mountain meadows have shown marked differences in response to N (Lewis and Lang *1957*). In Colorado, 'Garrison' creeping foxtail, 'Lincoln' bromegrass, and 'Oahe' intermediate wheatgrass produced maximum hay yields when cut July 5-18, July 5 to August 29, and after August 29, respectively (Siemer and Rumburg *1973*). Siemer and Rumburg cautioned that cutting species with differing seasonal growth curves on the same date may give a distorted picture of total yield and N response. For maximum response to applied N, it is essential to select the proper species and harvest at the proper growth stage.

Table 2.--*Nitrogen equivalent values of alfalfa, or amount of N required to produce grass yields equal to alfalfa-grass yields, (Boulder, 1958-62; and McFadden, 1959-61)*

Grass	Nitrogen equivalent	
	Boulder	McFadden
	----------*Lb N/acre*----------	
Garrison creeping foxtail	280	210
Common meadow foxtail	310	>230
Amur intermediate wheatgrass	230	110
Manchar smooth bromegrass	220	170
Russian wildrye	360	370
Reed canarygrass	230	---
Greenar intermediate wheatgrass	---	100
Regar meadow bromegrass	---	240

Note: Dashes indicate no data.

Crude protein content showed a variety of responses to increasing N rate at McFadden (fig. 4 and appendix table 3). Protein content of 'Garrison' creeping foxtail and 'Greenar' intermediate wheatgrass increased at an increasing rate as N rate increased. The protein content of creeping foxtail was consistently higher. Protein content of common meadow foxtail, 'Amur' intermediate wheatgrass, 'Manchar' smooth bromegrass, and 'Regar' meadow bromegrass increased linearly with increasing N rate, with no significant differences among species. Protein content of Russian wildrye responded erratically to N fertilization.

Nitrogen Rate, Date, and Source Study

N sources had no significant effects on hay yields. Similar results were reported in Colorado, where ammonium nitrate, S-coated urea, urea, and urea ammonium polyphosphate produced similar hay yields when applied at the same N rate (Ludwick and Rumburg *1975*, *1977*). Yields were higher with 160 lb N/acre than with 80 lb/acre at Big Piney and Laramie, but not at Daniel and Jackson (fig. 5). At Daniel, spring and split applications were superior to fall application at 160 lb N/acre, and split application was superior to fall application at 80 lb N/acre. There were no significant differences among application dates at the other three locations. Spring application of urea or ammonium nitrate has produced 10 percent higher yields than has fall application, but season of application of S-coated urea made no difference in yields (Seamands *1971*). Seamands suggested that differences between seasons of application might disappear on sites where greater snow cover and higher winter soil temperatures allowed some N uptake by plants during the winter. In Colorado, fall-applied N caused growth to start earlier than did spring-applied N, so that yields were higher from fall N, even though growth rates were the same for both seasons of application (Rumburg et al. *1980*).

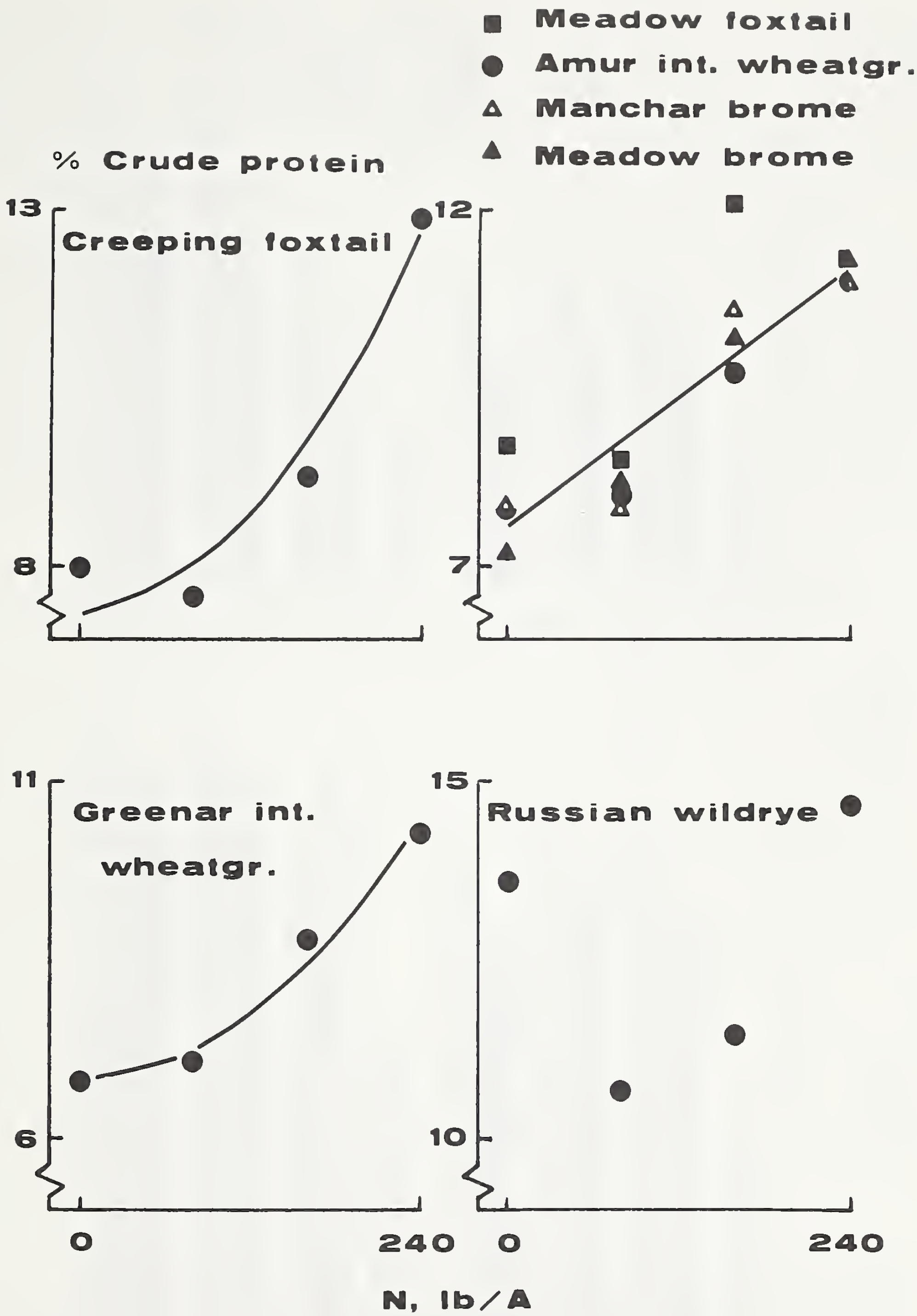

Figure 4.--Response of crude protein content of grass hay to 0, 80, 160, or 240 lb N/A (McFadden, 1959-61).

Whether to apply N to mountain meadows in spring or fall remains unresolved. We need greater knowledge of N movement, transformations, and losses in the unique soil ecosystem of high-altitude wet meadows. This system is characterized by high organic matter content, nearly continuous saturation with

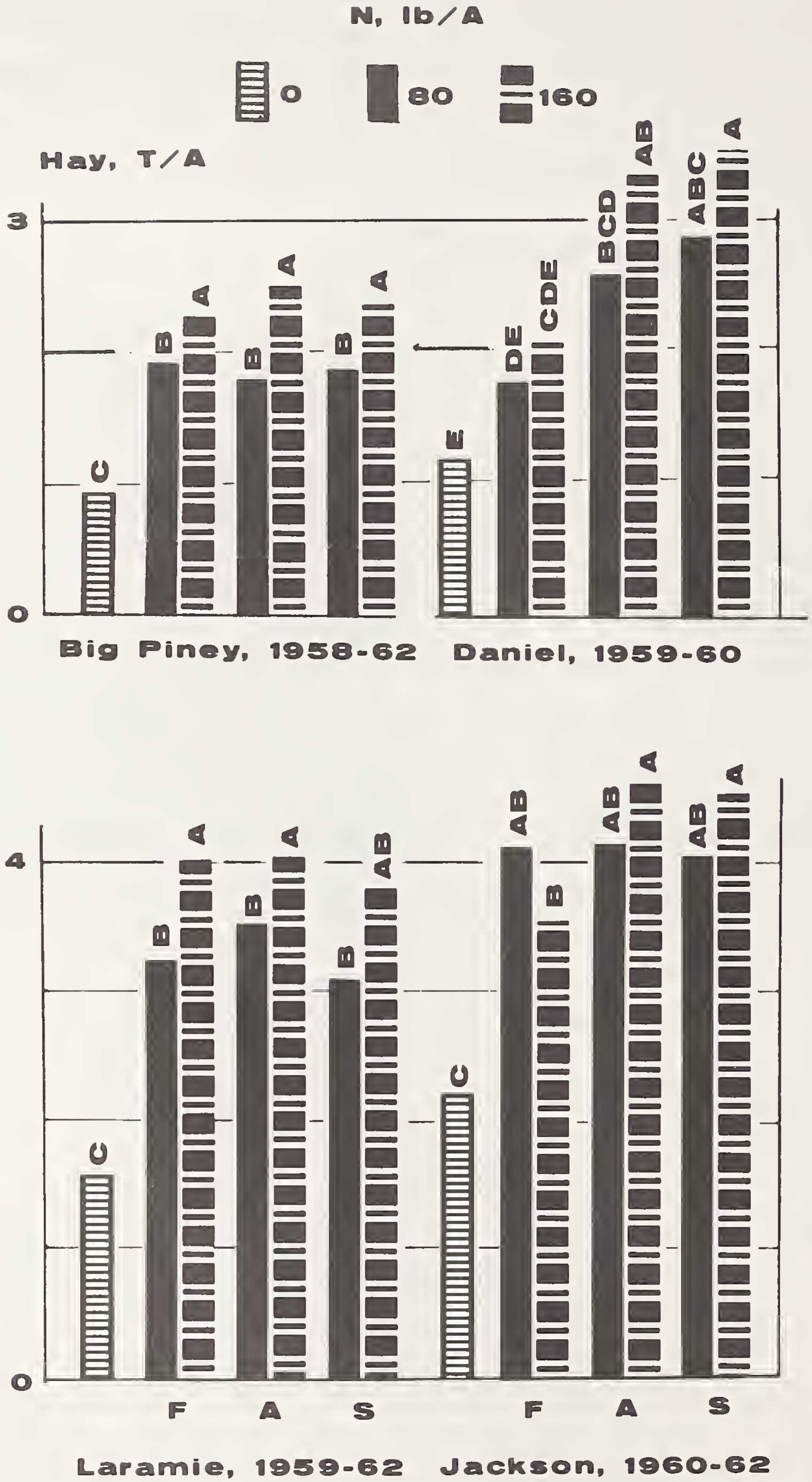

Figure 5.--Response of mountain meadow hay yields to N rate and season of application (F = fall, A = April, S = split application in April and June; yields at the same location labeled with the same letter are not significantly different).

water, and low soil temperatures. All these factors exert unquantified influences on the biotic and abiotic factors that control cycling, movement, and availability of N and other nutrients. Until these factors are better understood, and given the small and inconsistent differences among seasons of application, ranchers will probably continue to apply N whenever meadows are dry enough, the chore fits most conveniently into other ranch operations, and N is the lowest price.

Enough years of data were available from Big Piney and Laramie to show the influence of air temperature on N response, averaged over sources and dates of application. Temperature was expressed in cumulative degree days above a base of 40°F. For example, if mean temperature on a given day was 70°F, 30 degree days were accumulated. As the number of degree days increased, hay yields also increased up to a point, after which yields decreased but at a slower rate than that of the initial increase (figs. 6 and 7). Such a temperature response fits a curve of the type $y = a - b(t^c) - dt$; where y = yield, t = degree days, and a, b, c, and d are calculated constants which differ between locations and N

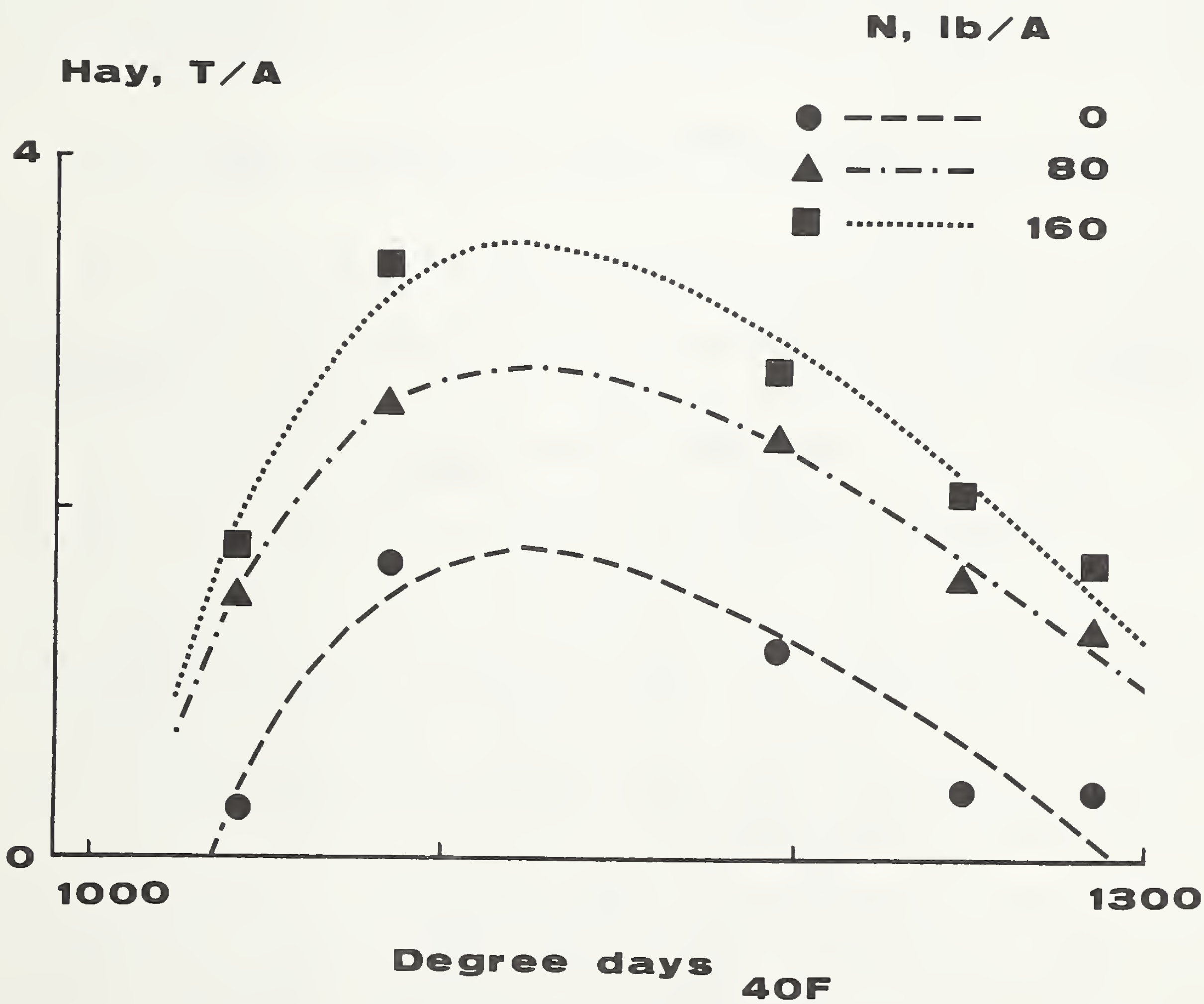

Figure 6.--Response of mountain meadow hay yields to temperature and N rate (Big Piney, 1958-62)

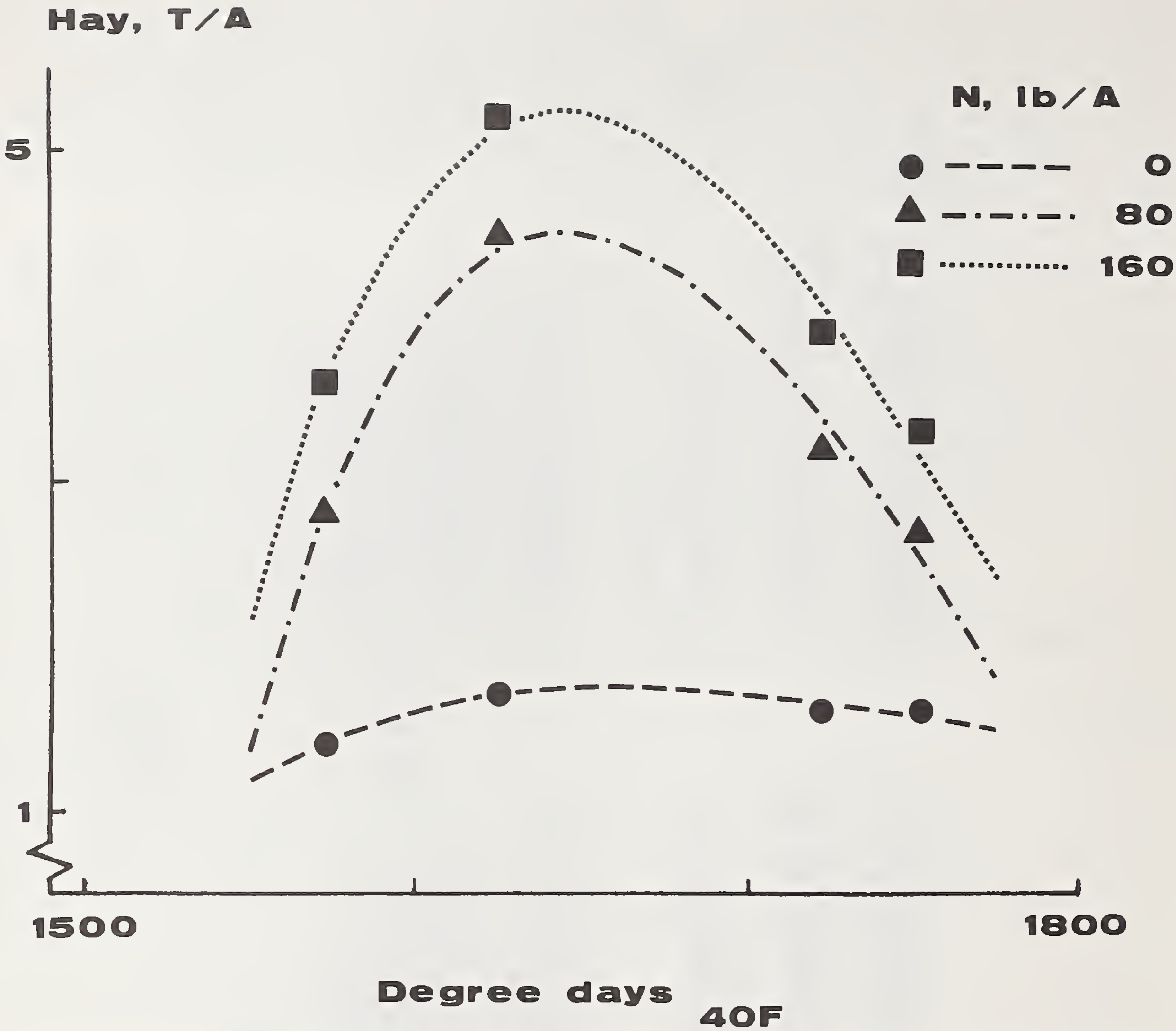

Figure 7.--Response of mountain meadow hay yields to temperature and N rate (Laramie, 1959-62)

rates. Fit of the data to such curves was excellent (appendix table 8). Maximum yield was predicted at 1,125 degree days at Big Piney and 1,650 degree days at Laramie. Differences between N levels tended to maximize at maximum yield. Degree days were a much better predictor of yield than was mean temperature in our studies, although mean temperature proved to be a good predictor in Colorado (Siemer et al. *1972*) and degree days are closely correlated with mean temperature (Siemer and Heermann *1970*).

Crude protein content was not affected by N source. At Big Piney, N application reduced forage protein content, except when 160 lb N/acre was applied in a split application (table 3). At Daniel, fall application of 160 lb N/acre produced lower protein content than did spring or split application, but none of the fertilization treatments produced protein content significantly different from that of the check. Protein content of the check treatment was not determined at Laramie and Jackson, so only comparisons between N treatments are

possible. Fall application usually produced lower protein content than spring or split application at these two locations. At all locations except Daniel, split application of 160 lb N/acre produced higher protein content than split application of 80 lb N/acre, but there were no differences between these two rates with spring or fall applications at any location. Alfalfa in the stand probably increased the protein content of forage at Daniel.

At Big Piney, the percentage of applied N recovered in forage varied more among dates of application and years when 80 lb N/acre was applied than when 160 lb N/acre was applied (fig. 8). When N was applied in the fall, N recovery was higher from the lower N rate; however, when N was applied in spring or split applications, recovery was higher from the higher N rate in 1958, and there were no differences between rates in 1962. These were the same 2 years in which recovery from fall application of 80 lb N/acre was greater than recovery from spring or split application of 80 lb N/acre. These 2 years and 1959, in which recovery was about the same for all three dates of application, were cooler than 1960 and 1961. In 1958, 1959, and 1962 degree days totaled 1084, 1042, and 1195, respectively, vs. 1248 and 1284 degree days in 1960 and 1961. The cooler temperatures may have inhibited N uptake from spring and split applications to levels no greater than uptake from fall N, in spite of overwinter losses of fall-applied N. This inhibition was overcome to some degree by higher rates of N.

Grasses, Legumes, Nitrogen and Phosphorus Rates, and Irrigation Methods

Under subirrigation, responses of bromegrass, reed canarygrass, and orchardgrass to N and temperature in this study (fig. 9 and appendix table 9) were similar to responses of native meadows at Big Piney and Laramie in the preceding study. Yields increased as the number of degree days increased toward optimum, then decreased at a slower rate, and differences between N rates tended to be greatest at optimum temperatures. Meadow foxtail and creeping foxtail yields were poorly correlated with temperature, perhaps indicating a broad range of optimum temperature conditions, which included those of this experiment. Yields of native meadow increased with increasing temperatures, with evidence of approaching a maximum only at 200 lb N/acre. Maximum yields of native meadow at Laramie and Big Piney were achieved at 1650 and 1125 degree days, respectively, whereas the greatest number of degree days recorded at Pinedale was 1204, so perhaps temperatures or growing seasons were inadequate for maximum yield of native meadow species at Pinedale. The soil, plant, and other climatic factors that determine temperature conditions for optimum yield have not been defined.

Yields of grasses were not significantly affected by irrigation method in 1965-67, but by 1968 yields of all introduced species except reed canarygrass were much less under continuous flooding when 200 lb N/acre was applied (table 4). Under continuous flooding, yields of smooth bromegrass were no higher with 200 lb N/acre than with 50 lb N/acre, apparently because stands were so reduced that there were insufficient plants to take advantage of the additional N. Orchardgrass was completely wiped out by continuous flooding. On the other hand, stands of flood-tolerant species such as reed canarygrass and the native grasses and sedges were unaffected by continuous flooding, and they responded similarly to N under both irrigation methods. Other workers have found that stands of introduced grasses decreased under continuous flooding to be replaced by native

Table 3.--*Crude protein content of forage from mountain meadows; effect of nitrogen rate and season of application*

N rate (lb/acre)	Season applied	Big Piney 1958-62	Daniel 1959-60	Laramie 1959-62	Jackson 1960-61
		Percent			
0	---	10.6 a[1]	11.2 a	---	---
80	Fall	9.4 b	11.5 a	7.7 b	7.0 c
	April	9.1 b	11.8 a	7.4 b	8.2 b
	April, June	9.5 b	11.8 a	7.4 b	8.2 b
160	Fall	9.0 b	10.8 a	7.8 b	6.9 c
	April	9.1 b	11.7 a	8.3 ab	8.1 b
	April, June	10.6 a	11.7 a	9.0 a	9.7 a

[1] Protein contents at the same location followed by the same letter are not significantly different based on the 0.05 level of Duncan's multiple range test.

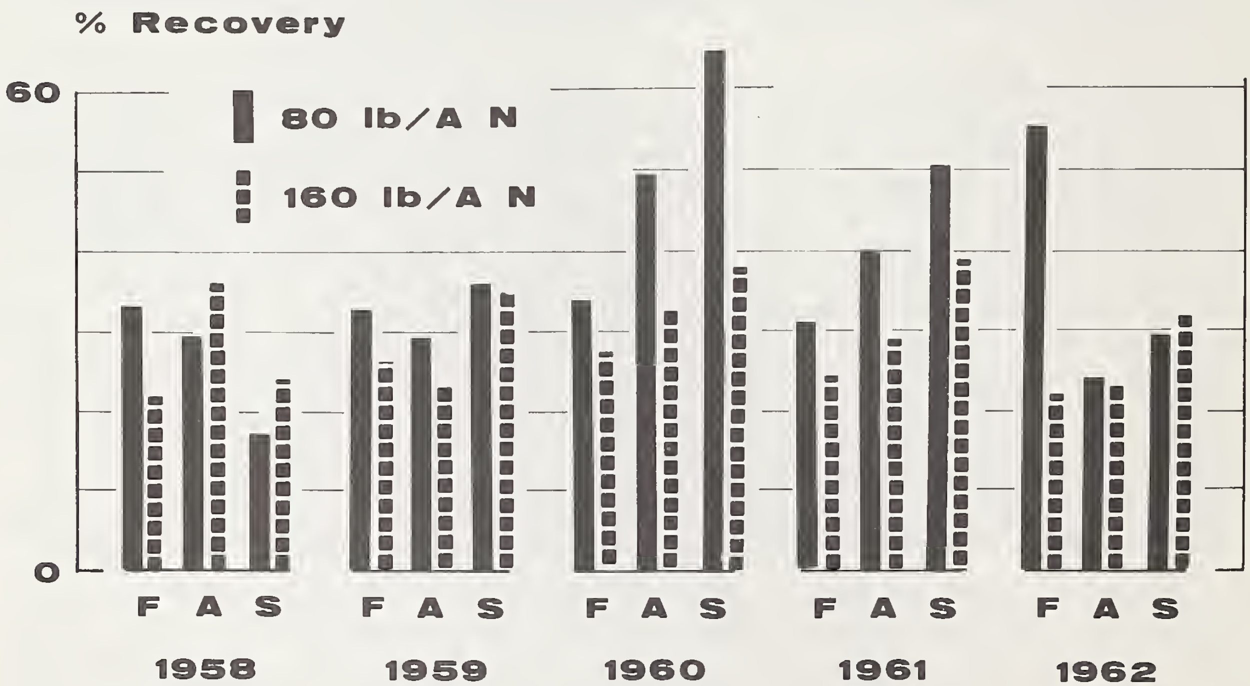

Figure 8.--Nitrogen recovery on mountain meadows at two N rates and three seasons of application (F = fall, A = April, S = split application in April and June; Big Piney).

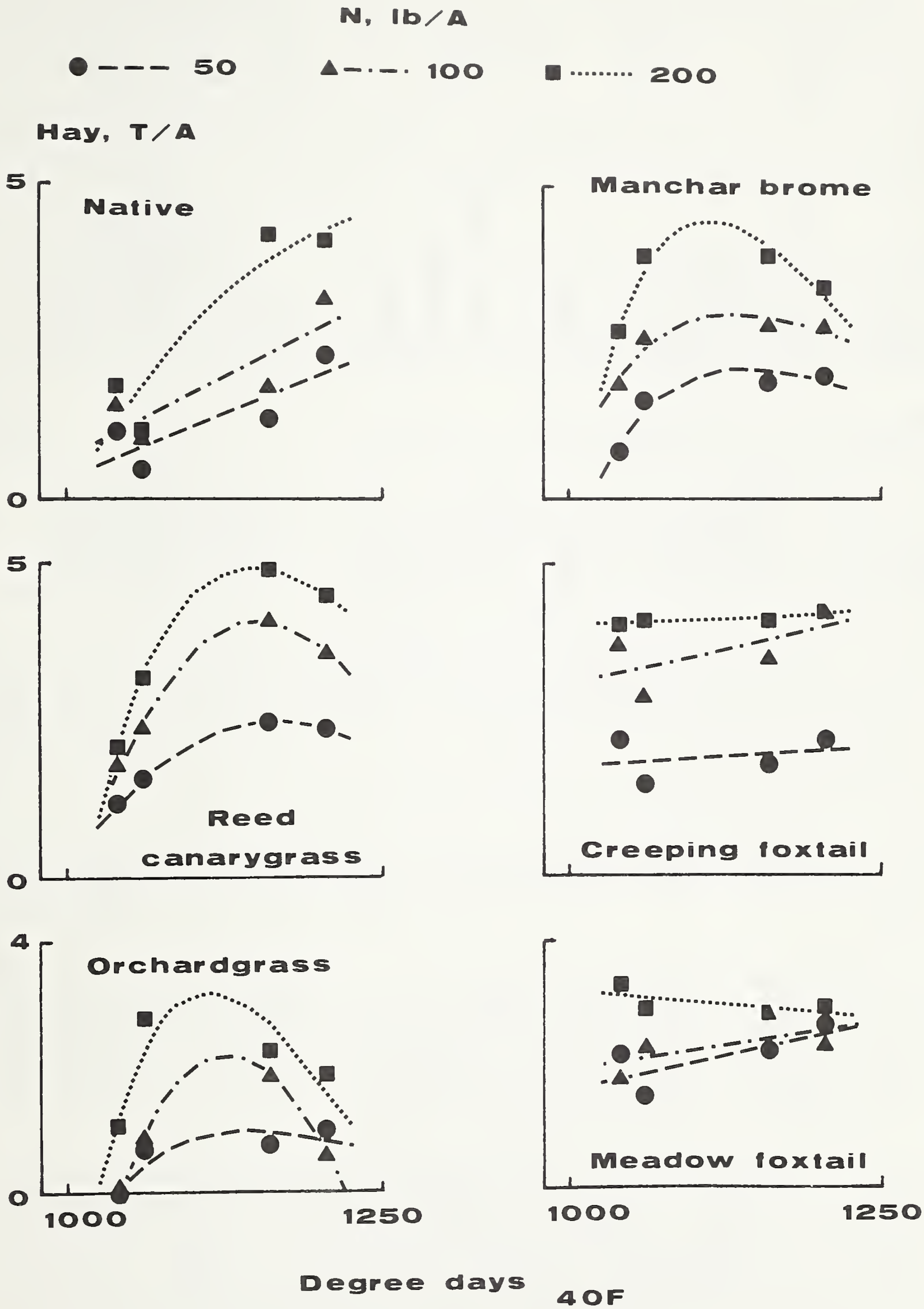

Figure 9.--Response of grass hay yields under subirrigation to temperature and N rate (Pinedale, 1965-68).

Table 4.--*Effect of irrigation method and nitrogen rate on grass yields (Pinedale, 1968)*

Grass	Irrigation method	N (lb/acre) 50	100	200
		Tons per acre[1]		
Creeping foxtail	Subirrigated	1.5 hi	2.9 bcde	4.1 a
	Continuous flood	1.3 ij	2.4 efg	3.0 bcd
Meadow foxtail	Subirrigated	1.5 hi	2.3 fg	2.9 bcde
	Continuous flood	1.1 ijk	1.2 ijk	2.0 fgh
Reed canarygrass	Subirrigated	1.6 hi	2.4 efg	3.2 bc
	Continuous flood	2.0 gh	3.3 b	3.1 bc
Orchardgrass	Subirrigated	.7 k	.9 jk	2.8 bcde
	Continuous flood	.0 l	.0 l	.0 l
Smooth bromegrass	Subirrigated	1.6 hi	2.6 cdef	3.9 a
	Continuous flood	.6 k	2.5 defg	1.1 ijk
Native	Subirrigated	.5 k	1.0 jk	1.1 ijk
	Continuous flood	1.1 ijk	1.0 jk	1.7 hi

[1]Yields followed by the same letter are not significantly different based on the 0.05 level of Duncan's multiple range test.

sedges and rushes (Siemer and Rumburg *1975*, and Lewis *1957*), and that grasses, sedges, and rushes tend to replace legumes under continuous flooding (Rouse et al. *1955*).

Alsike clover produced significantly more hay than red clover or cicer milkvetch when 85 lb P/acre was applied (fig. 10). Red clover and cicer milkvetch hay yields were unaffected by rate of P fertilization, but applications of 85 lb P/acre significantly increased alsike clover yields in 1967 and 1968. Yields of alsike with and without P, respectively, were 2.5 and 0.8 tons/acre in 1967 and 1.5 and 0.6 tons/acre in 1968.

Because only three rates of N were applied to the grasses, we did not compute an N response equation, and could not calculate an N equivalent value for legume-grass mixtures; however, it was possible to compare yields of the mixtures with yields of grasses alone at each level of N (fig. 10). Generally, each additional increment of N produced a significant increase in grass hay yields (50 and 100 lb N/acre produced similar yields of meadow foxtail), and yields of alsike clover-grass and red clover-grass mixtures were not significantly different from yields of the same grass fertilized with 50 lb N/acre; however, meadow foxtail plus either clover produced as much hay as meadow fox-

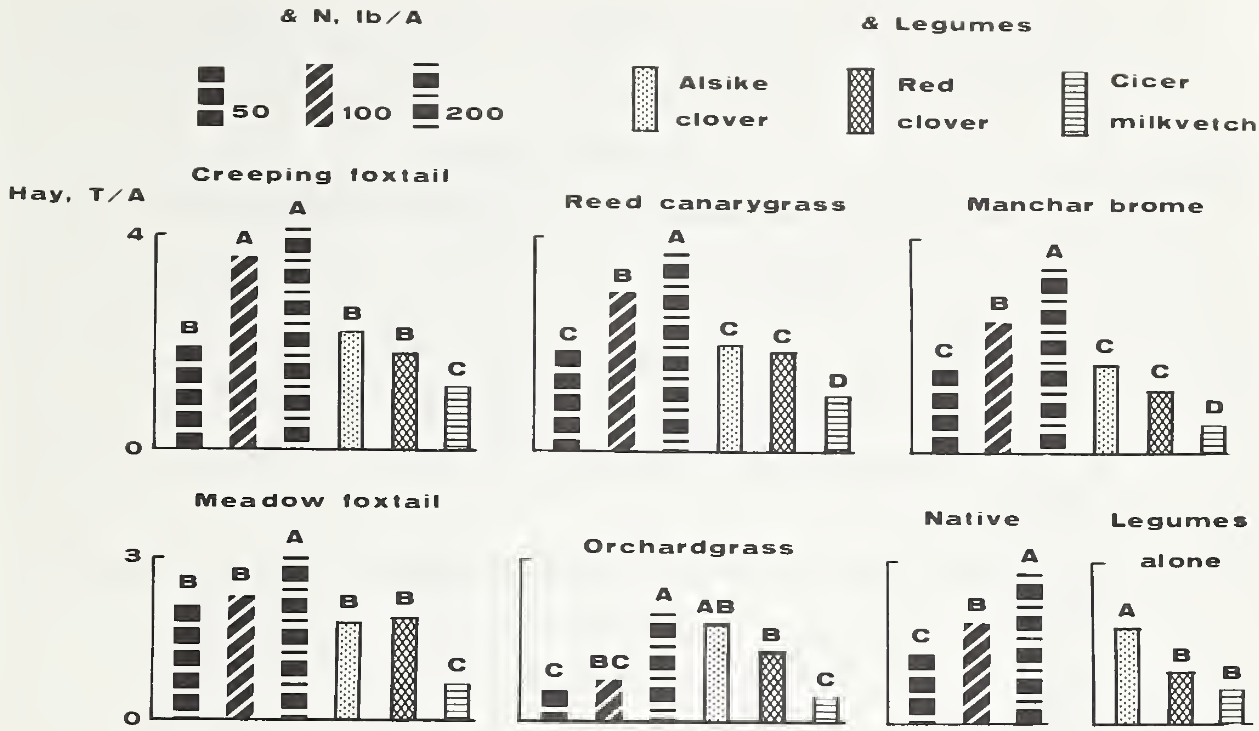

Figure 10.--Hay yields under subirrigation of introduced grasses and native meadow plus 50, 100, or 200 lb N/acre, of grass-legume mixtures, and of legumes plus 85 lb P/acre (Pinedale, 1965-68; yields within a grass species or within legumes labeled with the same letter are not significantly different).

tail plus 100 lb N/acre, orchardgrass-alsike clover produced as much as orchardgrass plus 200 lb N/acre, and orchardgrass-red clover produced as much as orchardgrass plus 100 lb N/acre. Cicer milkvetch-grass produced less than grass plus 50 lb N/acre, except for orchardgrass.

When 85 lb P/acre was applied annually, alsike clover and cicer milkvetch responded to temperature in much the same way as subirrigated bromegrass, reed canarygrass, and orchardgrass, but red clover yields increased linearly with increasing temperature (fig. 11 and appendix table 10). Hay yields of alsike clover-grass mixtures were poorly correlated with temperature, largely because of the fluctuating percentage of clover in the stand. No measurements were taken, but year-to-year fluctuations were readily observed. For example, total degree days in 1965 and 1968 were nearly the same, 1041 and 1060, respectively, but yields of reed canarygrass-alsike clover in the same years were 2.7 and 1.0 tons/acre, respectively. By 1968, alsike clover had nearly disappeared from plots of creeping foxtail and reed canarygrass, which are vigorous competitors. The amount of red clover in the mixtures also fluctuated somewhat, but yields were fairly well correlated with temperature. Only orchardgrass-red clover mixtures showed the same linear response to temperature as did pure stands of red clover. Cicer milkvetch was present in mixtures in small but fairly constant amounts, and yields of milkvetch-grass mixtures were very closely correlated with accumulated degree days.

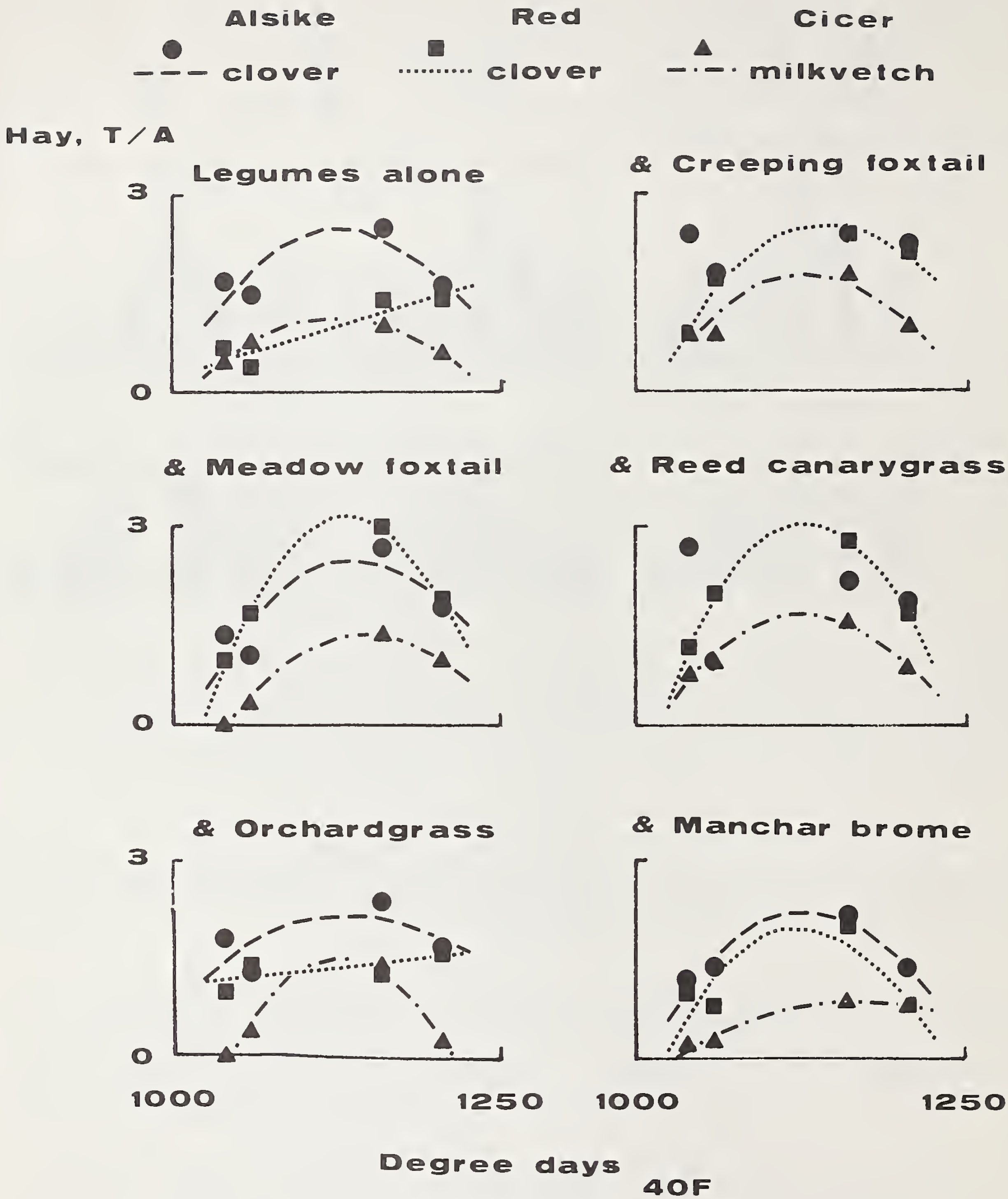

Figure 11.--Response of legume and grass-legume hay yields under subirrigation to temperature (Pinedale, 1965-68).

Under subirrigation, crude protein content of both foxtails and smooth bromegrass increased significantly with each increment of applied N (fig. 12).

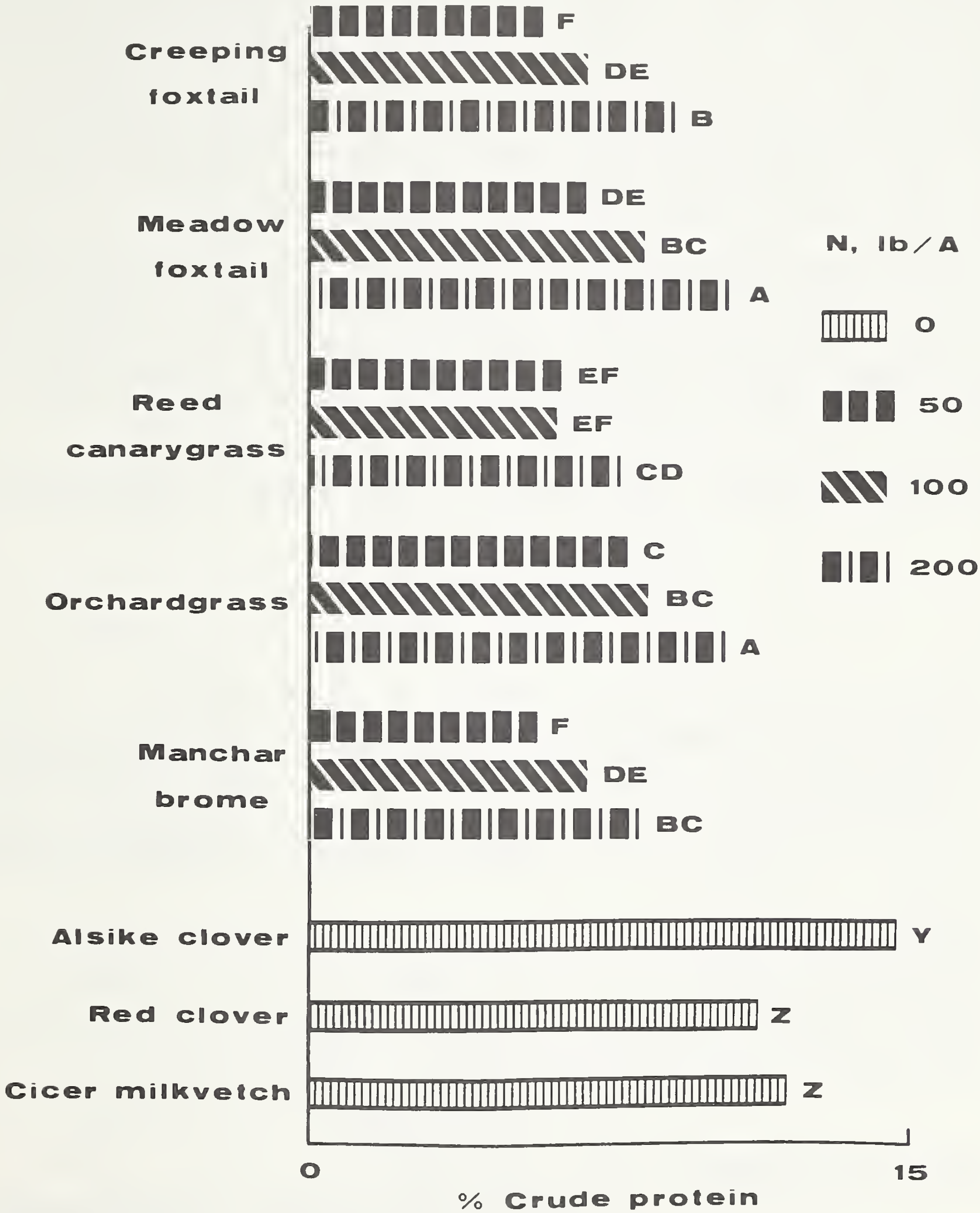

Figure 12.--Crude protein content under subirrigation of introduced grasses plus 50, 100, or 200 lb N/acre, and of legumes plus 85 lb P/acre (Pinedale, 1966-67; means within grasses or within legumes, labeled with the same letter, are not significantly different).

Protein content of reed canarygrass and orchardgrass did not increase significantly when N increased from 50 to 100 lb/acre, but was higher at 200 lb N/acre than at the two lower rates. Protein content of reed canarygrass and orchardgrass was usually higher than that of the other three grasses at all N rates, with few differences between reed canarygrass and orchardgrass or among the other three grasses. Protein content of reed canarygrass was lower under subirrigation than under continuous flooding (5.7 vs. 7.9 percent, respectively), whereas protein content of smooth bromegrass was higher under subirrigation (8.0 vs. 6.0 percent, respectively). Irrigation method did not affect protein content of the other grasses. Crude protein content of alsike clover was higher than that of red clover or milkvetch, and protein content of all three legumes was higher than that of any of the grasses at any N rate.

Creeping foxtail encroached more rapidly on the surrounding native meadow than any other grass species (fig. 13). Except for orchardgrass, which did not spread at all, there were no important differences in the rate of spread of the other grasses until 1968. By 1968, reed canarygrass had spread farther than smooth bromegrass under subirrigation and farther than meadow foxtail under either irrigation method. Creeping foxtail always spread faster under sub-

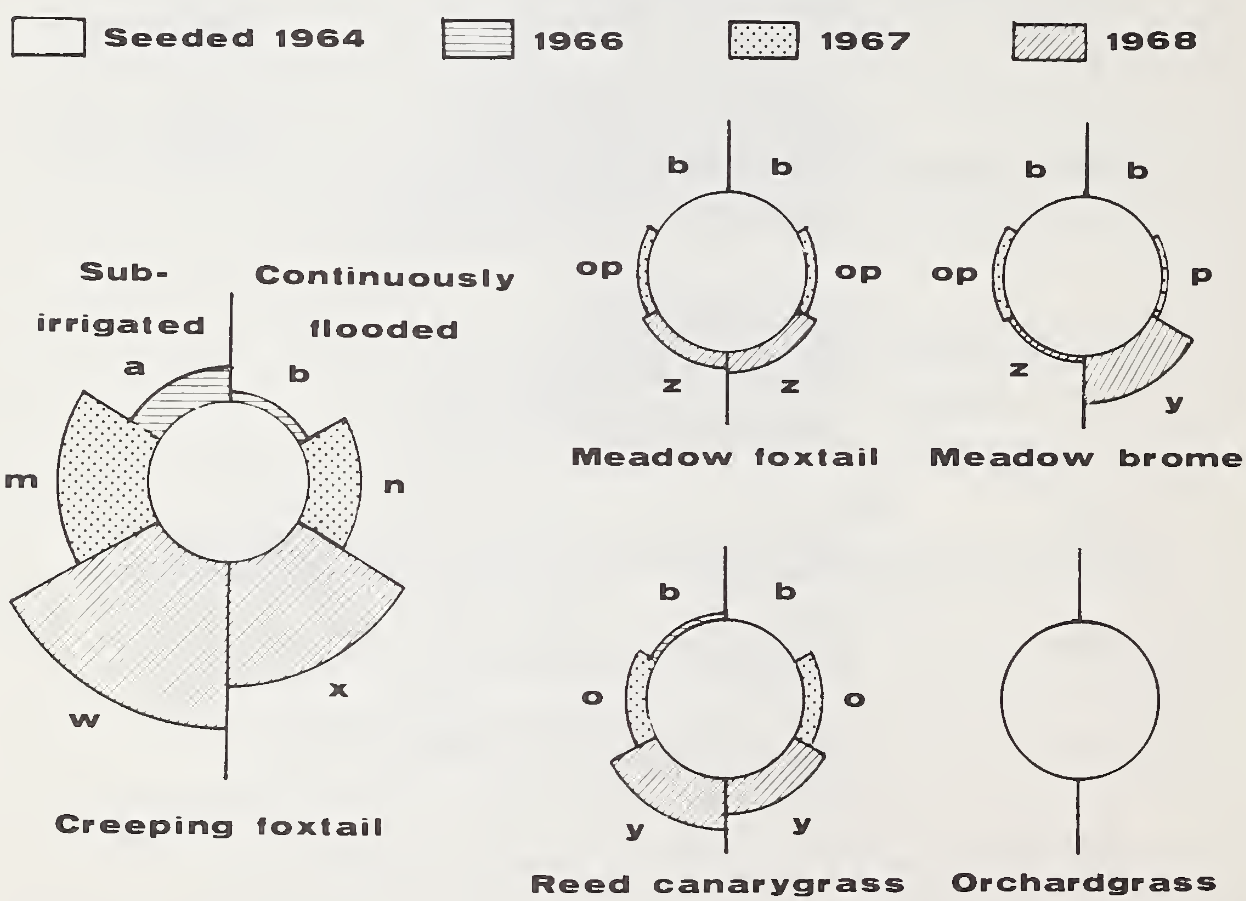

Figure 13.--Spread of grasses seeded into a mountain meadow (1 inch = 32 inches; Pinedale, 1964-68; distances labeled with the same letter in the same year are not significantly different).

irrigation than under continuous flooding, whereas by 1968 smooth bromegrass had spread farther under continuous flooding. Irrigation method had no effect on spreading of meadow foxtail, reed canarygrass, or orchardgrass. The rapid spread of creeping foxtail, coupled with high hay production, makes it highly desirable for meadow reseeding. Even a thin stand would spread in a few years to occupy most of the meadow.

The Blaney and Criddle method with modified coefficients (Kruse and Haise *1974*) was used to calculate total evapotranspiration for 1966 and 1967. Estimates were 28.0 and 27.4 inches, respectively. A similar estimate of 32.0 inches was derived from Kruse and Haise's regression of evapotranspiration on altitude. This regression was developed at latitudes of 38° to 39° North, and may have overestimated water use at our latitude of 42° North. When May-September precipitation of 3.5 and 5.0 inches for 1966 and 1967, respectively, were subtracted from the Blaney-Criddle estimates, irrigation requirements for 1966 and 1967 were estimated as 24.5 and 22.4 inches; however, measurements showed that 194 and 587 inches were applied, and after subtracting runoff, 130 and 299 inches had moved through the profile in 1966 and 1967, respectively. Therefore, 11.3 and 41.0 times the irrigation requirements were applied, and 5.3 and 13.3 times the requirement moved through the soil. Thus, in addition to reducing stands and hay production of several desirable grasses, continuous wild flooding was enormously wasteful of water and certainly contributed to leaching of applied N.

CONCLUSIONS AND RECOMMENDATIONS

Introduction of high-producing, moisture-tolerant grass species, such as creeping foxtail, meadow foxtail, reed canarygrass, meadow bromegrass, and intermediate wheatgrass, will increase forage production of mountain meadows far above that of unimproved native meadows; however, water control is essential for maintenance and maximum production of introduced grass and legume species. Control must include provision for drainage as well as control of water application through sprinkler or surface distribution systems.

With proper water control, introduced grasses will respond to N rates up to 240 lb/acre. Under controlled or limited irrigation, alfalfa-grass mixtures will yield as much as pure grass receiving 100 to 300 lb N/acre and will survive for years. Cicer milkvetch and alsike and red clovers survived for several years under continuous subirrigation, but mixtures of these legumes with grasses rarely produced more forage than grass plus 50 lb N/acre. Selection of adapted legume species and water control are necessary if legume N is to replace increasingly expensive fertilizer N.

Season of application and N source had little consistent effect on hay yields, except when ammonium sulfate produced more hay than other sources, probably because soil was deficient in available S. Soils should be tested to identify which plant nutrients are limiting; then the appropriate fertilizer formulation should be selected. In the absence of strong evidence to the contrary, fertilizer should be applied when soil moisture conditions permit and when the operation fits best into the schedule of other ranch operations.

Crude protein content of forage was sometimes increased by N fertilization, but not always. Source and date of application of N had little effect on protein content.

Air temperature exerts a major influence on forage production and response to nitrogen; both high and low temperatures may reduce yield and N response. The relationships among average, extreme, and optimum temperatures should be considered in formulating recommendations, but optimum temperature must be determined empirically because insufficient information exists to enable us to predict it from soil and climatic data.

Several significant gaps exist in our knowledge of mountain meadow forage production: (1) We must develop cost-efficient, environmentally sound methods of renovating or reseeding meadows. (2) We must learn how nutrient cycles operate in meadow soils to control nutrient movement, losses, and availability under existing temperatures and hydrologic conditions. (3) We must define how nutrient availability, climatic factors, and soil-water relationships interact to control plant growth, phenology, and forage yield and quality in the mountain meadow ecosystem. (4) We must determine seasonal growth patterns to select optimum harvesting schedules, either by cutting or grazing, for each forage species. When all these findings are incorporated into a verifiable model of the high-altitude wet meadow ecosystem, it will be possible to make management recommendations which are biologically valid, economically advantageous, and environmentally beneficial.

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Appendix table 5.--*Scientific names of plant species*

Common name	Scientific name
Alfalfa	*Medicago sativa* L.
Alsike clover	*Trifolium hybridum* L.
Cicer milkvetch	*Astragalus cicer* L.
Clover lupine	*Lupinus tidestromi* Fred.
Creeping foxtail	*Alopecurus arundinaceus* Poir.
Intermediate wheatgrass	*Agropyron intermedium* (Host) Beauv.
Kentucky bluegrass	*Poa pratensis* L.
Meadow bromegrass	*Bromus biebersteinii* Roem. and Schult
Meadow foxtail	*Alopecurus pratensis* L.
Orchardgrass	*Dactylis glomerata* L.
Red clover (including mammoth and Siberian)	*Trifolium pratense* L.
Redtop	*Agrostis alba* L.
Reed canarygrass	*Phalaris arundinacea* L.
Rushes	*Juncus* spp.
Russian wildrye	*Elymus junceus* Fisch.
Sedges	*Carex* spp.
Sickle milkvetch	*Astragalus falcatus* Lam.
Smooth bromegrass	*Bromus inermis* Leyss.
Tall fescue	*Festuca arundinacea* Schreb.
Timothy	*Phleum pratense* L.
Tufted hairgrass	*Deschampsia caespitosa* (L.) Beauv.
White clover	*Trifolium repens* L.
Zigzag clover	*Trifolium medium* L.

Appendix table 6.--*Nitrogen response of mountain meadow hay yields (tons per acre), 1956-57*

Location	N source	Equation	R^2
Encampment	Anhydrous ammonia	$Y = 3.25 + 0.00421$ N	.86*
	Ammonium nitrate	$Y = 3.21 + 0.00793$ N	.89*
	Ammonium sulfate	$Y = 3.27 + 0.0101$ N	.98**
Laramie	All	$Y = 1.83 + 0.0127$ N	.95**
McFadden	Anhydrous ammonia	$Y = 2.00 + 0.0000491\ N^2$	.97**
	Ammonium nitrate	$Y = 2.11 + 0.00929$ N	.94**
	Ammonium sulfate	$Y = 2.15 + 0.00132\ N^2$	.99**
Saratoga	Anhydrous ammonia	$Y = 1.20 + 0.0114$ N	.99**
	Ammonium nitrate	$Y = 1.43 + 0.0111$ N	.84*
	Ammonium sulfate	$Y = 1.16 + 0.0160$ N	.99**

Appendix table 7.--*Nitrogen response of hay yield, crude protein content, and crude protein yield of grasses seeded into mountain meadows*

Grass species and variety	Boulder, 1958-62 Equation	R^2	McFadden, 1959-61 Equation	R^2
Hay yield (tons per acre):				
Garrison creeping foxtail	$Y = 0.12 + 0.0153\ N$	.99**	$Y = 0.56 + 0.0239\ N - 0.0000430\ N^2$	.99**
Common meadow foxtail	$Y = 0.35 + 0.0131\ N$	.98**	$Y = 0.19 + 0.0236\ N - 0.0000508\ N^2$	.99**
Amur intermediate wheatgrass	$Y = 0.50 + 0.0162\ N$	.99**	$Y = 1.19 + 0.0286\ N - 0.0000664\ N^2$	.98**
Manchar smooth bromegrass	$Y = 0.82 + 0.0171\ N$	.99**	$Y = 1.06 + 0.0221\ N - 0.0000352\ N^2$	.99**
Russian wildrye	$Y = -0.03 + 0.0090\ N$	.98**	$Y = 0.16 + 0.0070\ N$	.99**
Ioreed reed canarygrass	$Y = 0.32 + 0.0165\ N$	.99**		
Greenar intermediate wheatgrass			$Y = 1.14 + 0.0318\ N - 0.0000664\ N^2$	.99**
Regar meadow bromegrass			$Y = 0.82 + 0.0233\ N - 0.0000508\ N^2$	.99**
Protein (percent):				
Garrison creeping foxtail			$Y = 7.41 + 0.0000912\ N^2$	.96**
Common meadow foxtail, Amur intermediate wheatgrass, Manchar smooth bromegrass, and Regar meadow bromegrass			$Y = 7.61 + 0.0154\ N$	.78**
Greenar intermediate wheatgrass			$Y = 6.86 + 0.0000622\ N^2$	.98**
Russian wildrye			$Y = 12.01 + 0.00512\ N$	.08
Protein (pounds per acre):				
Garrison creeping foxtail			$Y = 101 + 2.60\ N$	.98**
Common meadow foxtail			$Y = 67 + 2.27\ N$	.99**
Amur intermediate wheatgrass			$Y = 223 + 2.71\ N$	.96**
Manchar smooth bromegrass			$Y = 277 + 3.20\ N$	.95**
Russian wildrye			$Y = 59 + 1.09\ N$	.93**
Greenar intermediate wheatgrass			$Y = 173 + 3.63\ N$	.99**
Regar meadow bromegrass			$Y = 143 + 2.61\ N$	.97**

Appendix table 8.--*Temperature response of mountain meadow hay yields (tons per acre) at three nitrogen levels (DD = degree days, base 40°F)*

Location and years	Nitrogen	Equation	R^2
	Lb/acre		
Big Piney, 1958-62	0	$Y = 22.04 - 7.440\ (10^{45})\ DD^{-15} - 0.01691\ DD$	.87*
	80	$Y = 22.96 - 7.294\ (10^{45})\ DD^{-15} - 0.01680\ DD$	.98**
	160	$Y = 28.20 - 9.006\ (10^{45})\ DD^{-15} - 0.02059\ DD$	.95**
Laramie, 1959-62	0	$Y = 11.64 - 1.289\ (10^{48})\ DD^{-15} - 0.00558\ DD$	.91*
	80	$Y = 91.40 - 9.558\ (10^{48})\ DD^{-15} - 0.04950\ DD$	.96**
	160	$Y = 92.47 - 9.436\ (10^{48})\ DD^{-15} - 0.04976\ DD$	.98**

Appendix table 9.--*Temperature response of grass hay yield (tons per acre) under three rates of nitrogen (Pinedale, 1965-68; DD = degree days, base 40°F)*

Species	Nitrogen	Equation	R^2
	Lb/acre		
Native	50	$Y = -7.69 + 0.008053\ DD$	.71
	100	$Y = -9.71 + 0.01038\ DD$	.74
	200	$Y = 141.12 - 8.887\ (10^{4})\ DD^{-1} - 0.05232\ DD$	.87*
Creeping foxtail	50	$Y = 0.59 + 0.001199\ DD$	.08
	100	$Y = -1.30 + 0.004370\ DD$	.40
	200	$Y = 3.11 + 0.0008881\ DD$	.72
Meadow foxtail	50	$Y = -2.40 + 0.004054\ DD$	.48
	100	$Y = -1.29 + 0.003215\ DD$	.38
	200	$Y = 5.06 - 0.001869\ DD$	.43
Reed canarygrass	50	$Y = 66.17 - 2.514\ (10^{10})\ DD^{-3} - 0.04100\ DD$	.99**
	100	$Y = 453.24 - 2.588\ (10^{5})\ DD^{-1} - 0.1949\ DD$	.99**
	200	$Y = 39.14 - 1.353\ (10^{37})\ DD^{-12} - 0.02756\ DD$	.99**
Orchardgrass	50	$Y = 7.99 - 3.467\ (10^{45})\ DD^{-15} - 0.005721\ DD$	.80
	100	$Y = 715.00 - 4.013\ (10^{5})\ DD^{-1} - 0.3165\ DD$	.99**
	200	$Y = 45.43 - 1.256\ (10^{46})\ DD^{-15} - 0.03570\ DD$	.69
Smooth bromegrass	50	$Y = 12.88 - 4.987\ (10^{45})\ DD^{-15} - 0.008860\ DD$	.90*
	100	$Y = 14.90 - 4.789\ (10^{45})\ DD^{-15} - 0.009875\ DD$	.89*
	200	$Y = 38.88 - 1.066\ (10^{46})\ DD^{-15} - 0.02902\ DD$	.88*

Appendix table 10.--*Response of hay yields (tons per acre) of legumes and legume-grass mixtures to temperature (Pinedale 1965-68, Y = yield in T/A, DD = degree days above a base of 40°F)*

Grass	Legume	Equation	R^2
None	Alsike clover	$Y = 328.43 - 183475\ DD^{-1} - 0.1448\ DD$	.62
	Red clover	$Y = -5.62 + 0.00591\ DD$	.84*
	Cicer milkvetch	$Y = 216.47 - 120831\ DD^{-1} - 0.0959\ DD$	.99**
Creeping foxtail	Alsike clover	$Y = 1.23 + 0.000872\ DD$	.06
	Red clover	$Y = 347.98 - 197416\ DD^{-1} - 0.1511\ DD$	.96*
	Cicer milkvetch	$Y = 334.52 - 187614\ DD^{-1} - 0.1475\ DD$	.79
Meadow foxtail	Alsike clover	$Y = 357.37 - 202077\ DD^{-1} - 0.1558\ DD$	.70
	Red clover	$Y = 631.47 - 355537\ DD^{-1} - 0.2776\ DD$	.99**
	Cicer milkvetch	$Y = 310.36 - 177042\ DD^{-1} - 0.1348\ DD$	.99**
Reed canarygrass	Alsike clover	$Y = 1.75 + 0.000180\ DD$	.01
	Red clover	$Y = 611.26 - 342279\ DD^{-1} - 0.2702\ DD$	.99**
	Cicer milkvetch	$Y = 323.65 - 181065\ DD^{-1} - 0.1431\ DD$	.93*
Orchardgrass	Alsike clover	$Y = 202.59 - 113556\ DD^{-1} - 0.0884\ DD$	.37
	Red clover	$Y = -1.31 + 0.00236\ DD$	.54
	Cicer milkvetch	$Y = 532.74 - 299122\ DD^{-1} - 0.2358\ DD$	.96**
Smooth bromegrass	Alsike clover	$Y = 373.48 - 209192\ DD^{-1} - 0.1647\ DD$	.92*
	Red clover	$Y = 440.69 - 246483\ DD^{-1} - 0.1952\ DD$	.65
	Cicer milkvetch	$Y = 108.70 - 62964\ DD^{-1} - 0.0462\ DD$	.98**

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